Optical Communications for HEP Detectors

USCMS Fellowship, Summer 2011

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Internship for USCMS

What is CMS?

High Energy Particle Physics Detector located underground as part of the LHC at CERN in Switzerland and France.

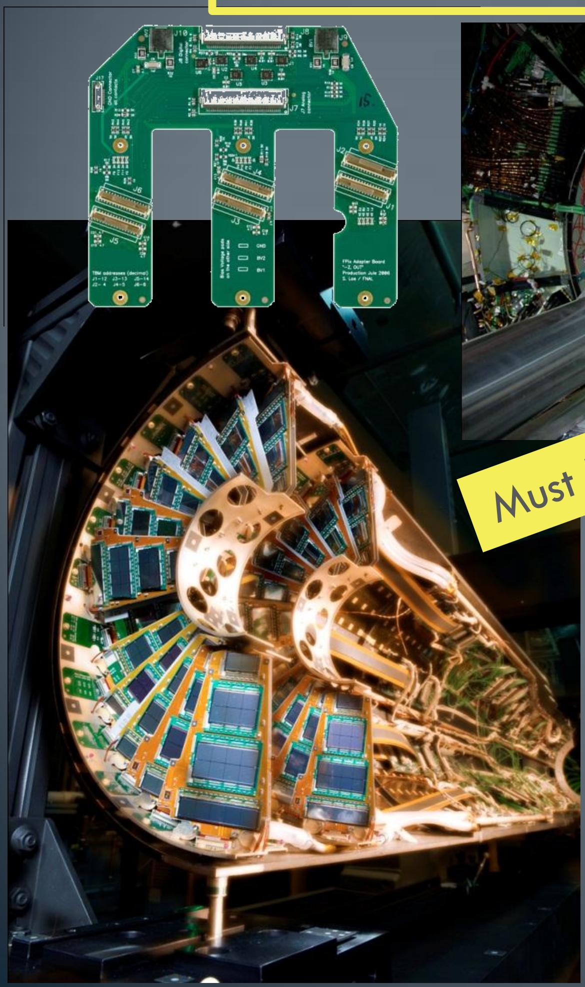
COMPACT MUON SOLENOID

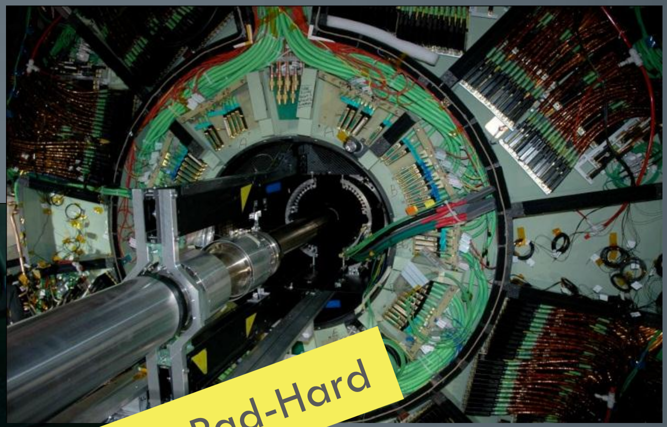
Photos from Fermilab VMS

What did I do?

Performed tests for both ON-Detector and OFF-Detector components.

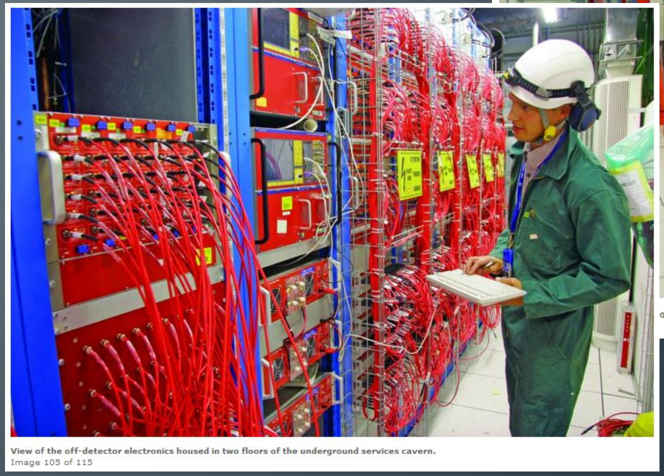
Front end (ON DETECTOR)





Must be Rad-Hard

Back end (OFF DETECTOR)



Pictures from Simon Kwan, Fermilab VMS & CERN media

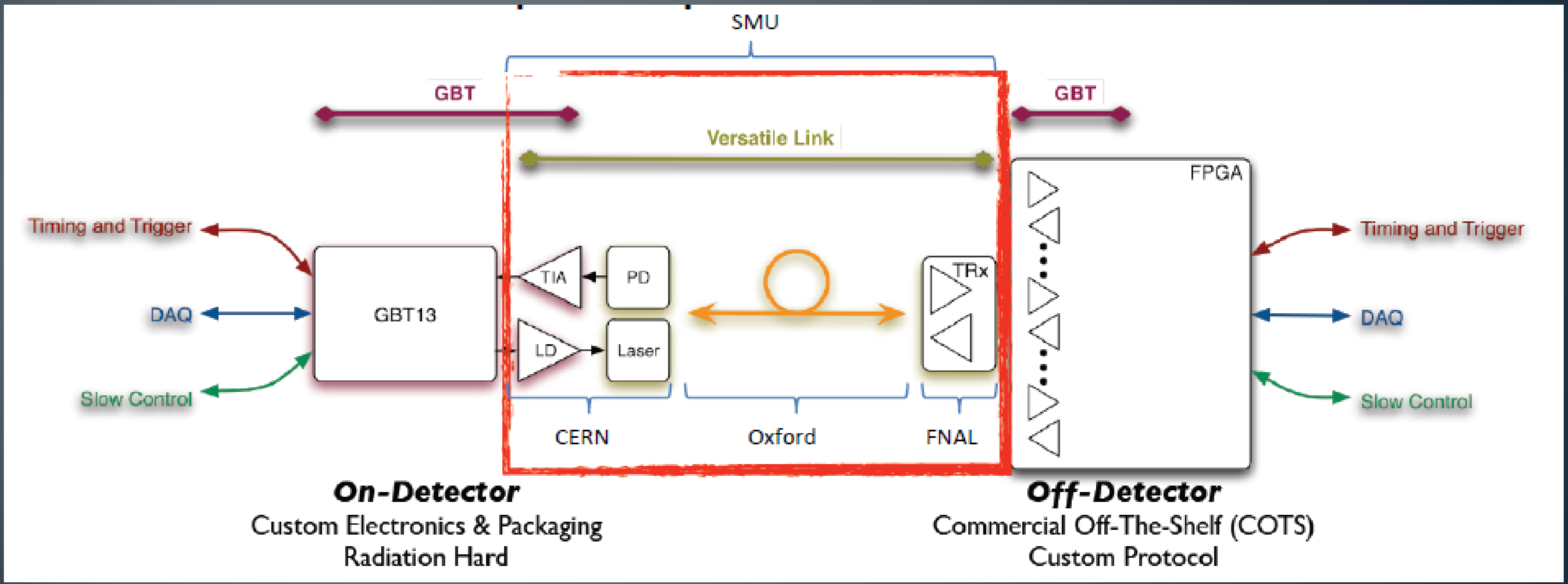
On the Back End
Versatile Link Common Project

OFF-Detector Components

Backend Components

- Testing commercial devices, Versatile Link Common Project
- Data taken from the detectors has to be read out and analyzed
- Readout is electrical and converted to optical

Information from Jan Troska, CERN



Versatile Link Common Project

CERN-organized common project for ATLAS and CMS Goal: "Development of a general purpose optical link which can cover all envisioned transmission applications: a versatile link" @ data transfer rates of up to 5 Gbps

Why optical Communications?

- Fast
- Low power

- Low loss over LONG distances
- High data-carrying capacity
- Low noise/crosstalk

In comparison to copper electrical wires

Current Commercial Devices

1 channel transceiver

Typical 10G Ethernet parts
(commercially available today)

CXP
devices

Evolution of Parallel Optical Devices

12 channel transceiver

Device in testing phase for vendor
(not available on market)

What are fiber optics?

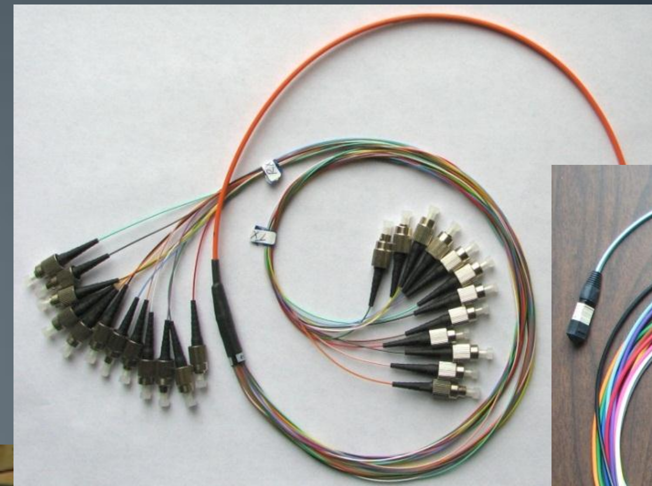
- Tx convert electrical to optical
- Cable (bundle of fibers)
- Rx convert back to electrical
- (information signal is digital)

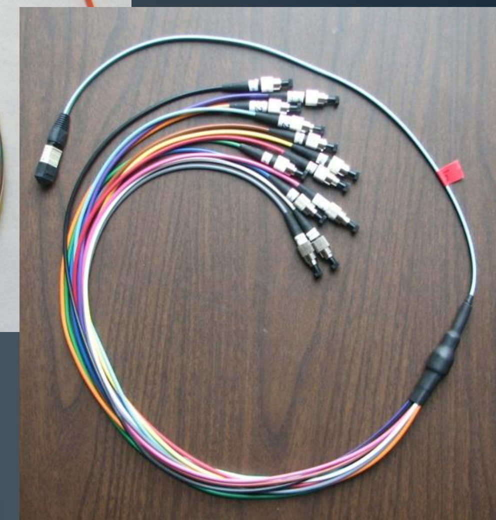
VLCP Tests Performed

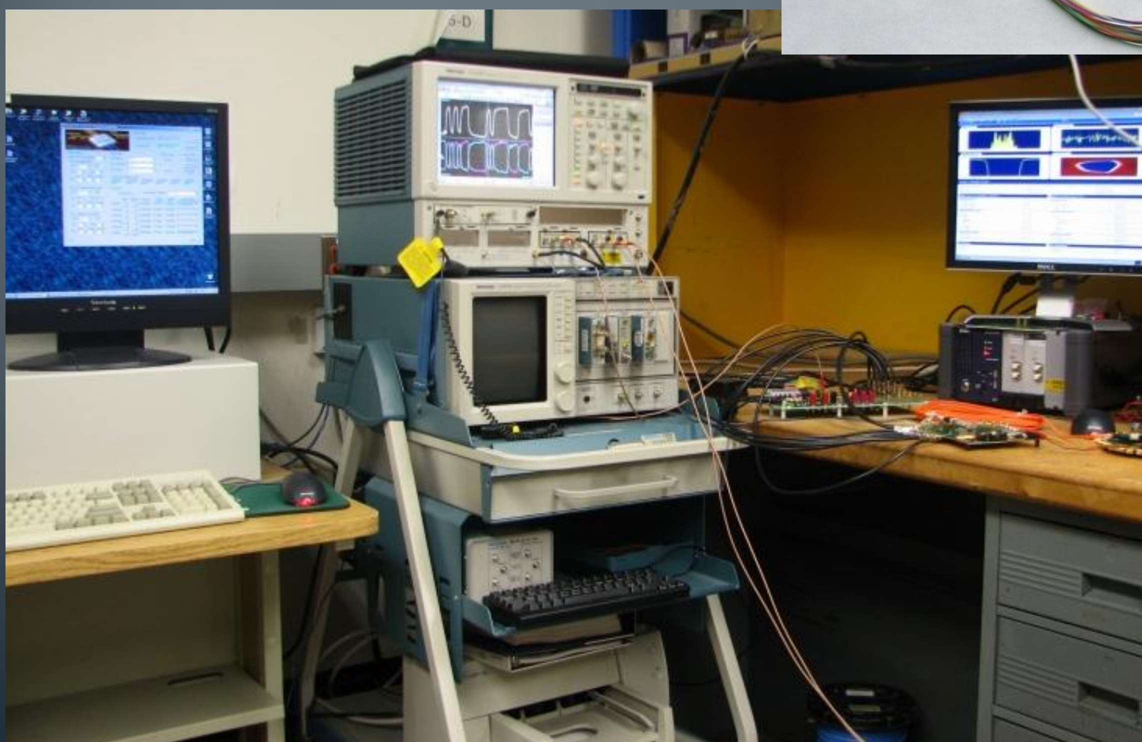
- at 5 Gbps & 10 Gbps
- over multimode (850 nm) and singlemode (1310 nm) fibers
- including multimode tests using 100m of fiber

Hardware for testing commercial devices:

- Breakout fibers – (testing individual channels)
- Test Set-Up (oscilloscope, variable optical attenuator, pulse generator, SMA cables, programmable power supply)





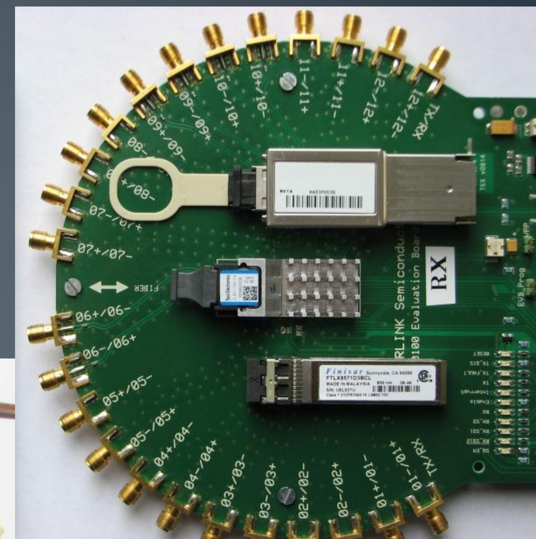


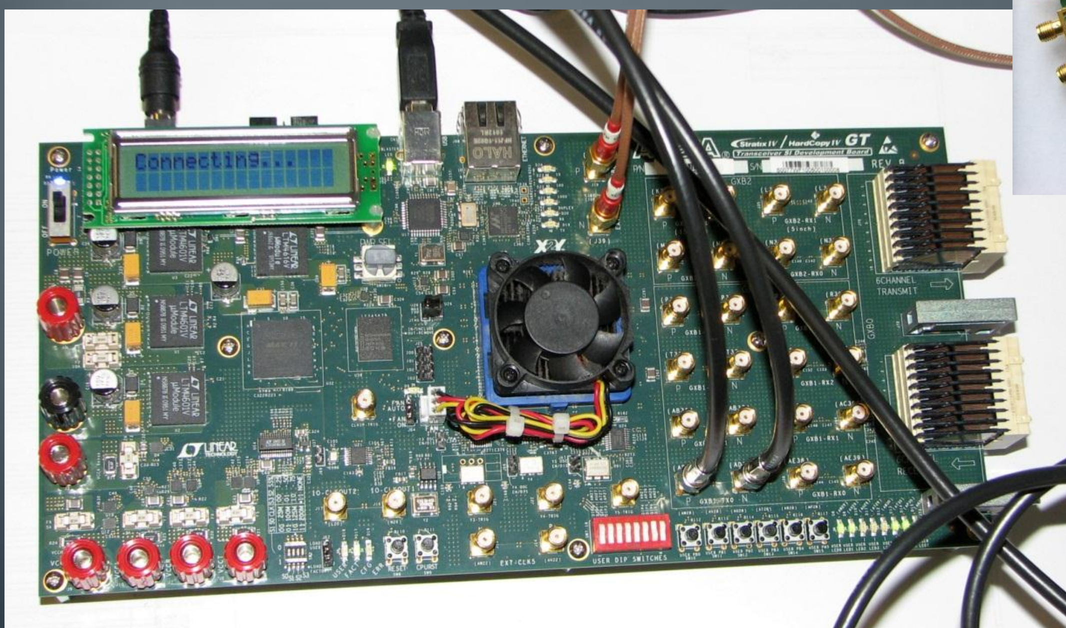
Fiber Optic Color Code Chart

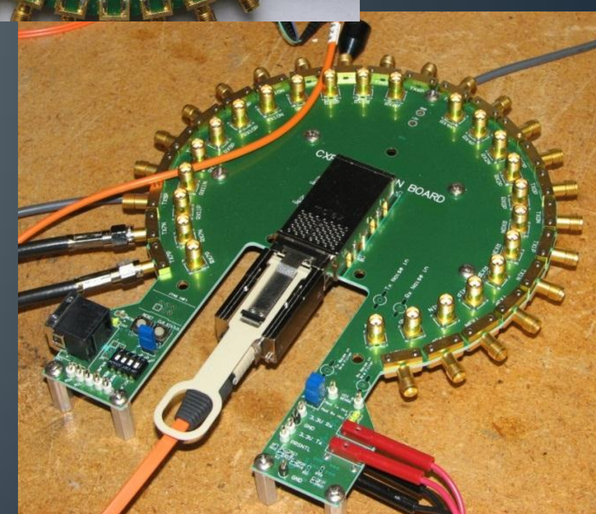
color	fiber #	figure	fiber #	color
blue	1		0	blue
orange	2		1	orange
green	3		2	green
brown	4		3	brown
slate	5		4	slate
white	6		5	white
red	7		6	red
black	8		7	black
yellow	9		8	yellow
purple	10		9	purple
rose	11		10	rose
aqua	12		11	aqua

Hardware for testing commercial devices:

- Multimode & singlemode fibers
- Evaluation Boards from Vendors
- SNAP 12 device
- CXP device
- FPGA signal integrity board (USB controlled)

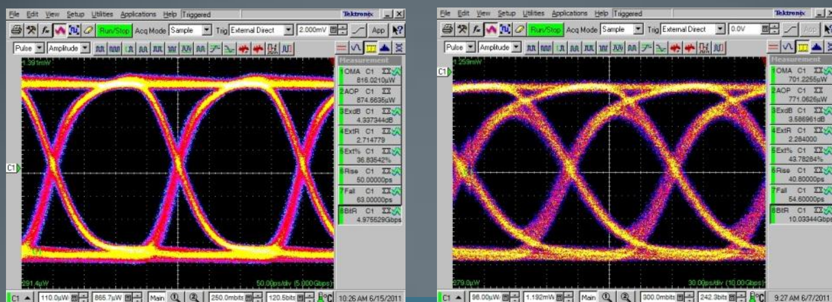




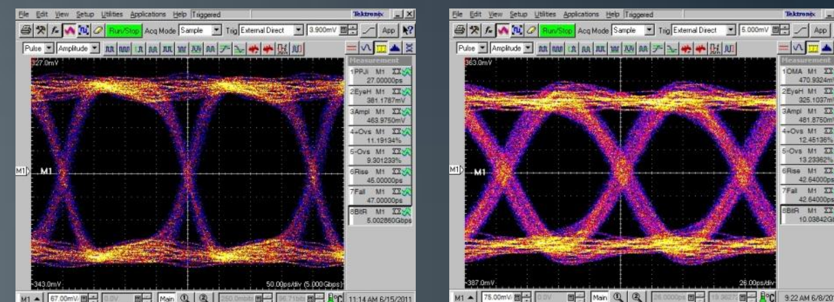


Basic Optical Measurements

- Tx & Rx **Eyes**
  - notice how eyes decrease at higher data transfer rates



Tx optical eyes at 5, 10 Gbps

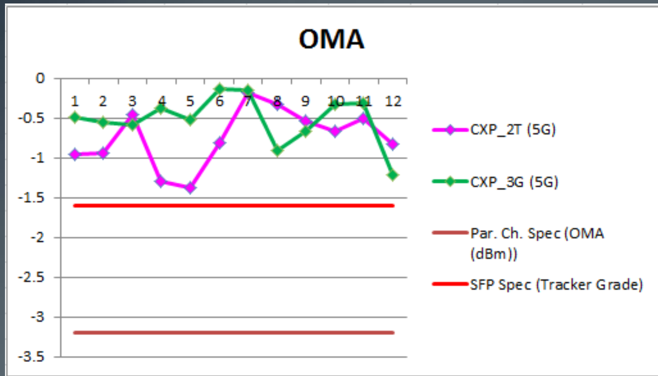


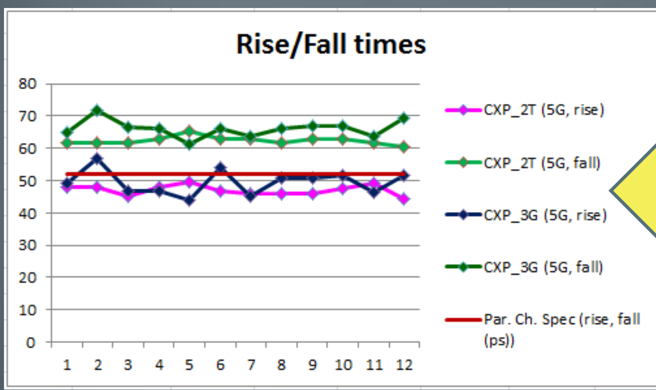
Rx electrical eyes at 5, 10 Gbps

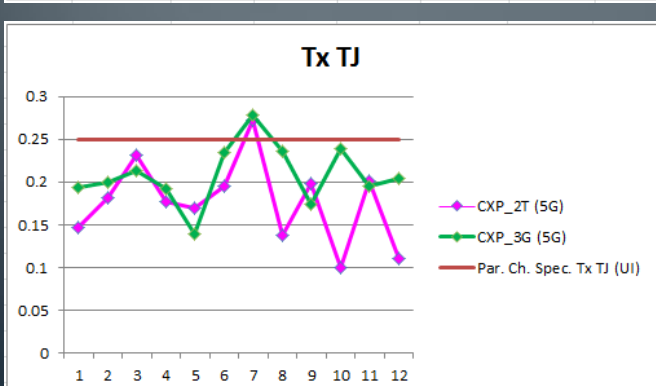
- **Jitter**
  - Jitter - deviation of signal in reference to a clock source
  - DJ PDF (deterministic jitter probability density function); DDJ (data dependent jitter); BER bathtub; BER Eye (1E-12)
- System Performance
  - **BERT** - bit error rate testing
  - **Receiver Sensitivity**

Jitter

Results of CXP testing at 5 & 10 Gbps

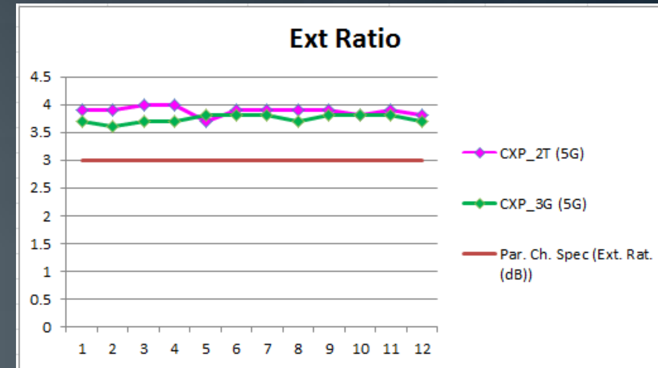


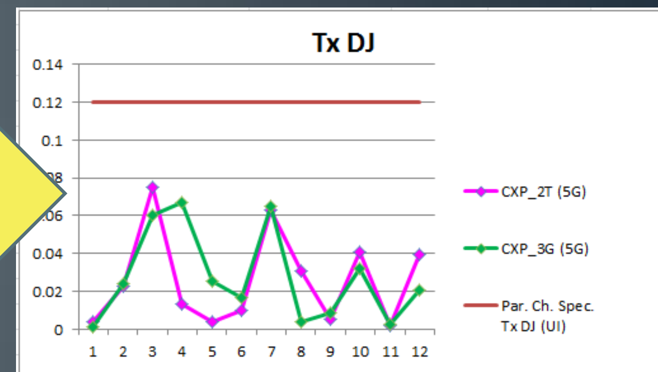


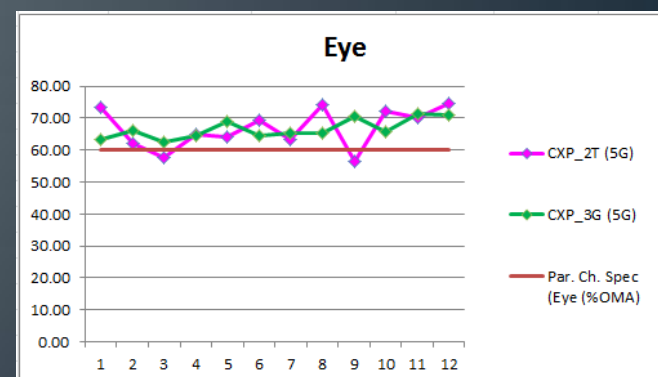


Plots to determine if the devices are meeting the desired specifications.

These were done for CXP devices at 5 and 10 Gbps.





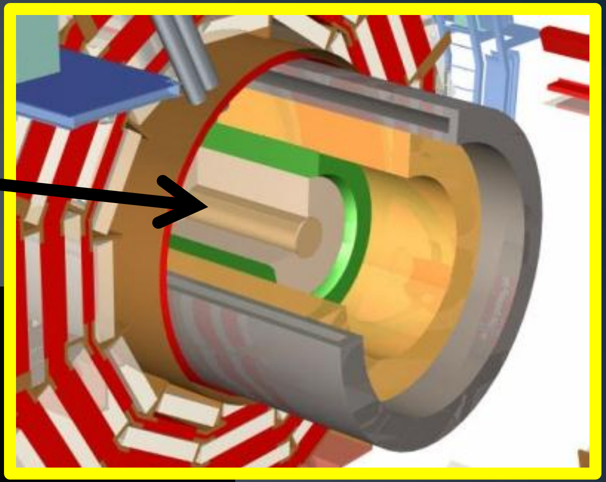


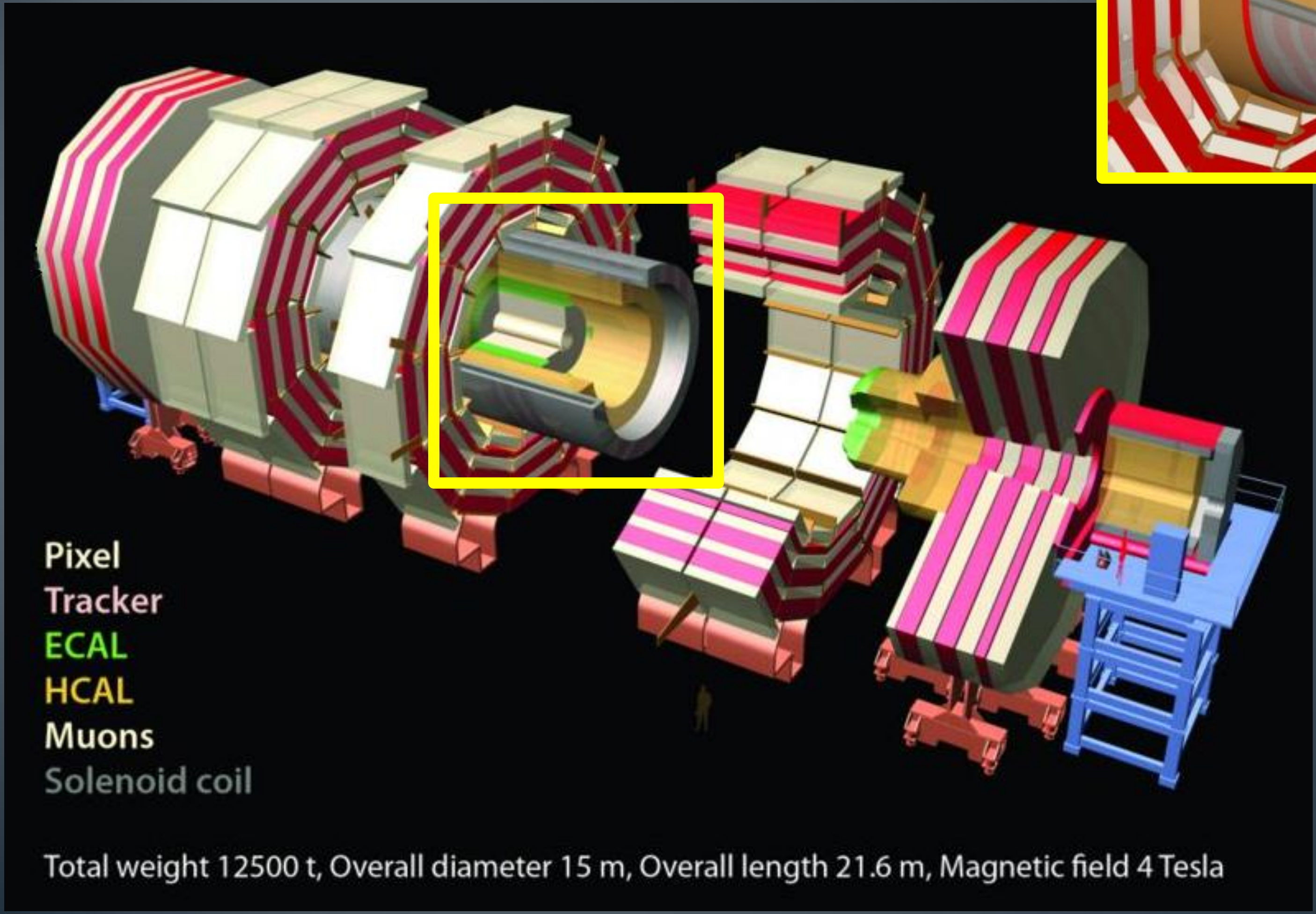
On the Front End
CMS Phase I Upgrades – Opto Hybrids

ON-Detector Components

CMS Experiment

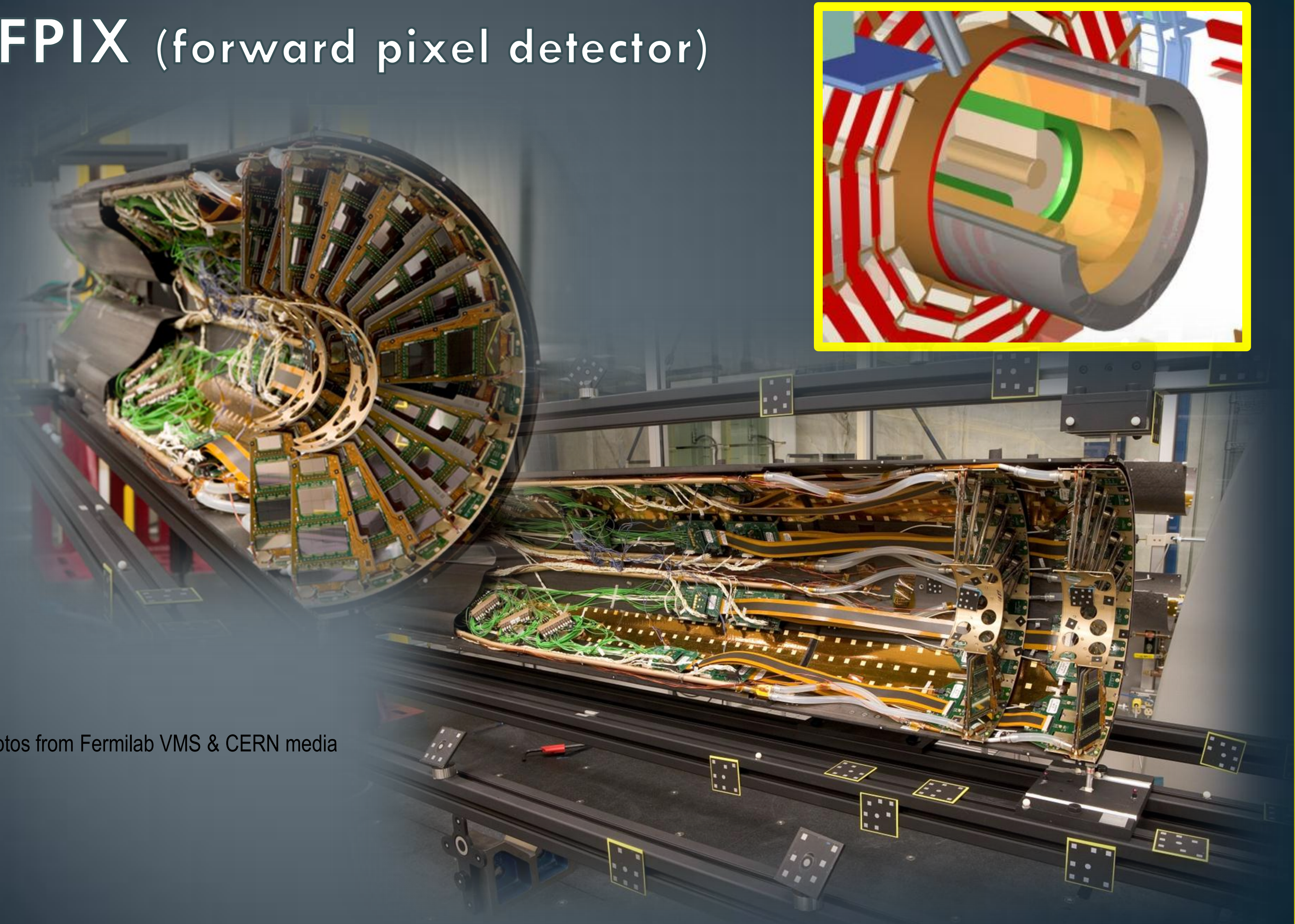
Forward Pixel Detector





Photos from CERN media

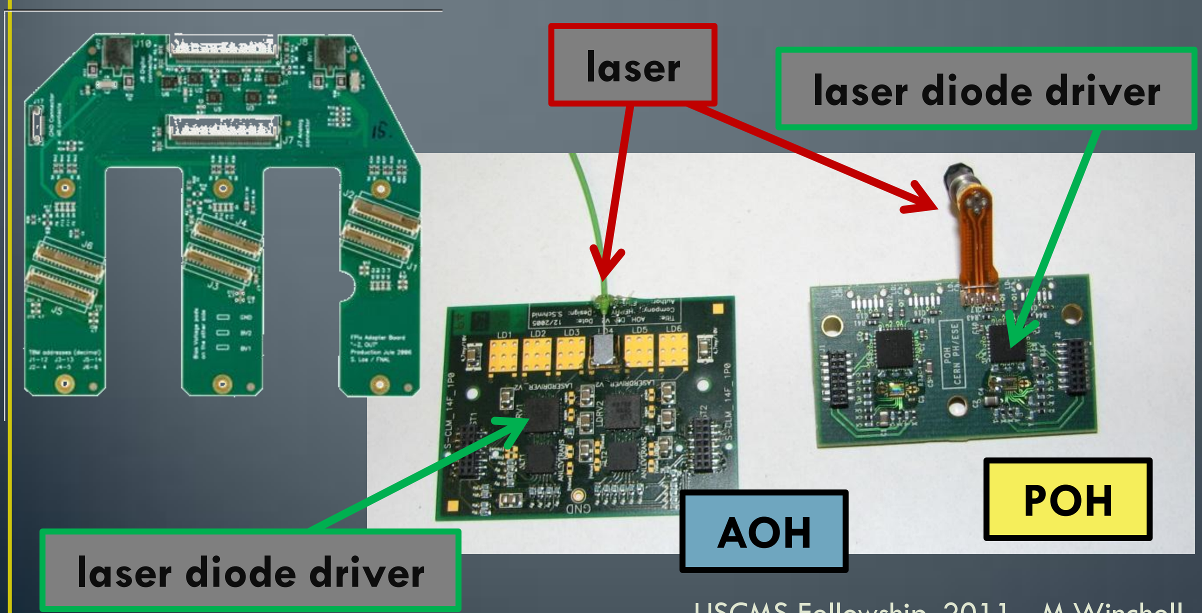
FPIX (forward pixel detector)



Photos from Fermilab VMS & CERN media

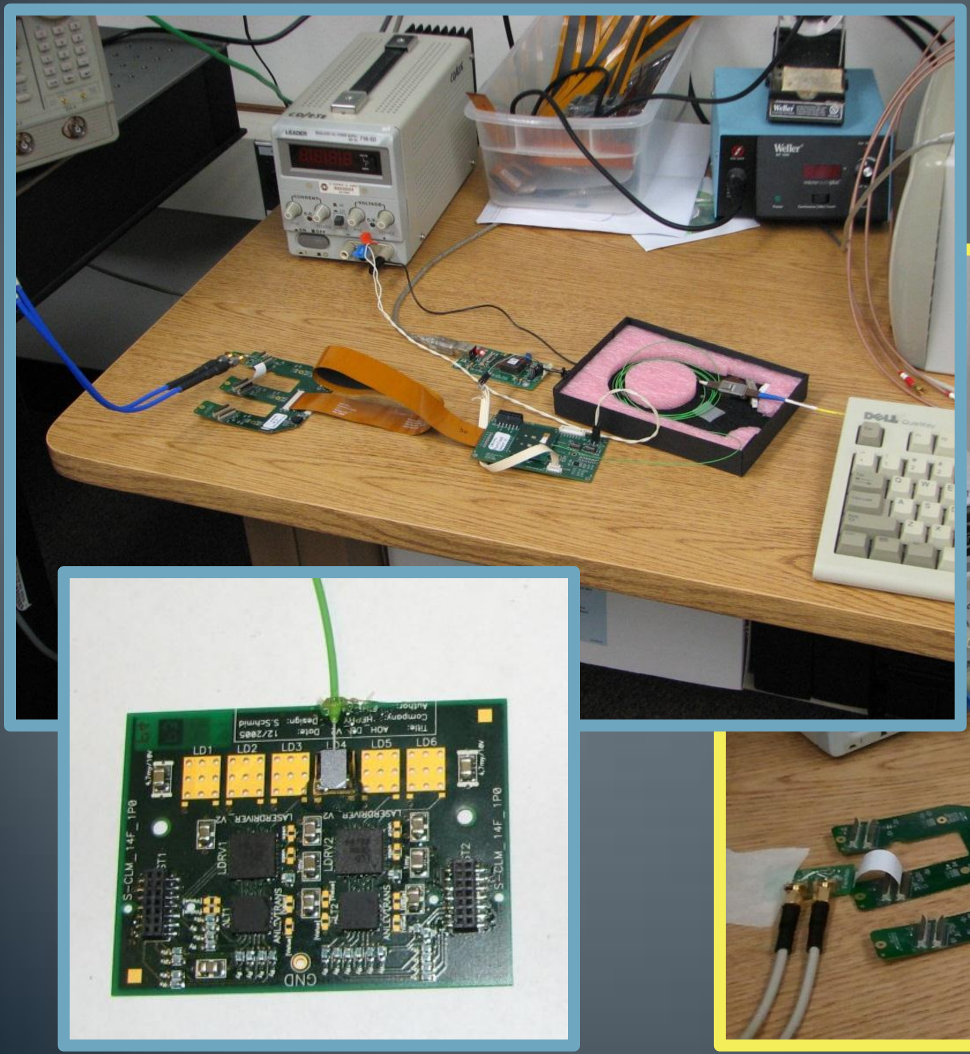
CMS Pixel Upgrades

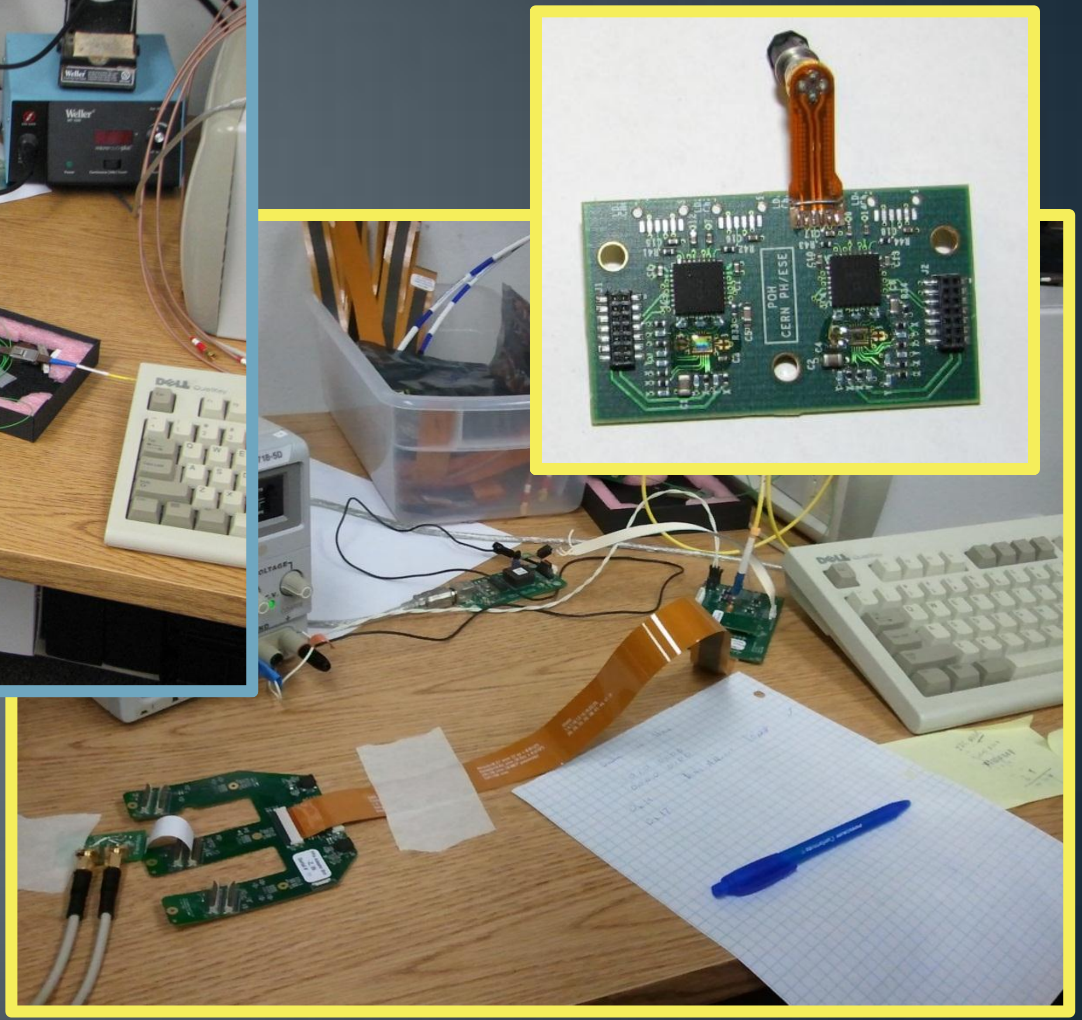
- Analog Opto-Hybrid (AOH) vs. Pixel Opto-Hybrid (POH)
  - Both have lasers to transmit light
  - Pixel upgrades will switch from AOH to POH
- Why a new POH?
  - Lasers not available anymore
  - Increased speeds
  - Digital format rather than analog



Opto Hybrid Readout Path

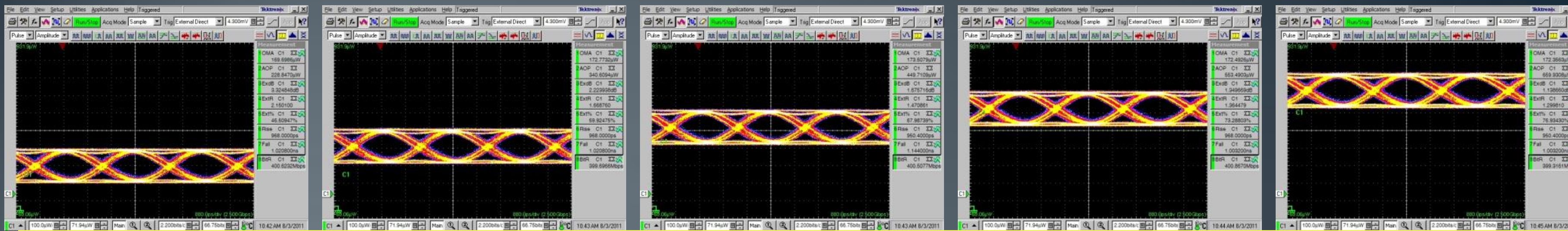
- Testing Set-Up: Current vs. Phase 1 Upgrade





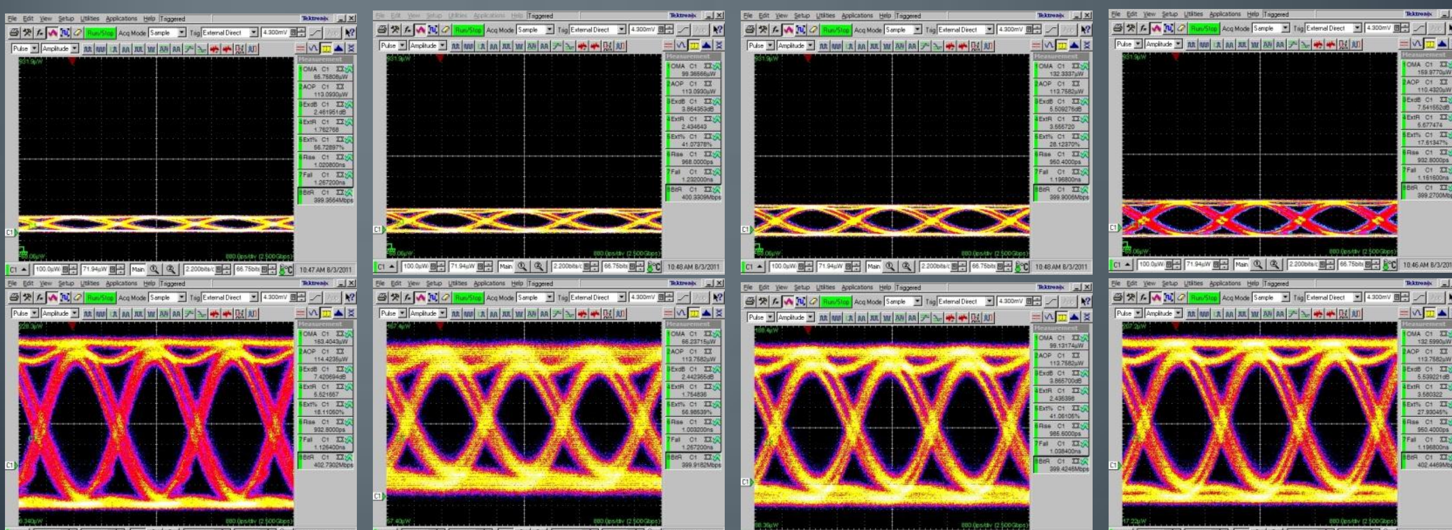
Measurements

- Laser Drivers have 2 controls to change the transmission of light



Bias Current – controls offset of light output (increased bias levels = increased light output)

- Bias levels from 30-70 (must boost current in order to reach a 1 or 0 at higher bias levels)



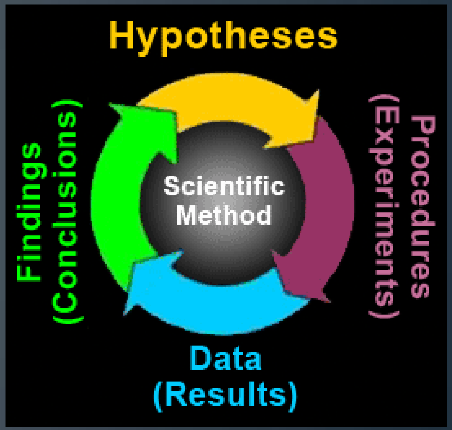
increasing gain or bias levels requires more current to the system

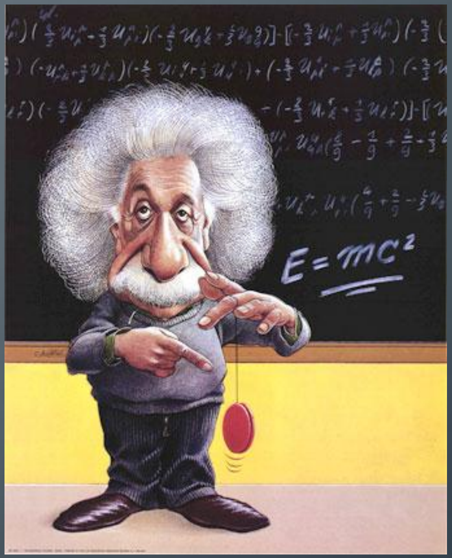
Laser Gain – controls signal amplitude (increased gain = larger eyes)

- Bias levels remained constant (20) at 4 different gain levels (0-3) – current is boosted with increased gain levels

Students: "Do I really need to know this?"

- Teacher: "Yes!"
  - Problems of probability and examples of use in research analysis (jitter distributions)
  - Research processes used "in real life"
    - Scientific methods used in research & development laboratories all over the world!
  - STEM Careers (science, technology, engineering, math)





Special Thanks

Fermilab

- Computing Division
- Future Programs and Experiments
- Electronic Systems Engineering Department
- Detector Instrumentation Group

- Simon Kwan, ESE Department Head
- Alan Prosser, DI Group Leader
- John Chramowicz
- Dan Karmgard, USCMS Education & Outreach Coordinator
- Harry Cheung, TRAC Program Manager

Questions?

Photographs & Information Courtesy of:

- From CERN media – CMS photo book
  http://cms.web.cern.ch/cms/Media/index.html
- Fermilab Visual Media Services
  http://www-visualmedia.fnal.gov/VMS_Site_2/index.shtml
- Simon Kwan, Fermilab
- Alan Prosser, Fermilab
- Jan Troska, CERN